Project Title: Predicting Lightning Risk

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Abstract: Lightning causes most wildfires in the western United States, and is a major cause of fire elsewhere in the U.S. Because most lightning occurs with significant precipitation, however, simple predictions of Lightning Activity Level (LAL) do not accurately determine fire ignition potential. We propose to incorporate existing weather predictions into tactical fire preparedness and planning by adapting a methodology to assess the risk of "dry" lightning (that which occurs without accompanying rainfall). Based on atmospheric moisture and stability variables, we will develop discriminant rules that assign a probability of dry lightning over the United States, using a method that we created and tested in the northwestern U.S. (Rorig and Ferguson 1999). The results will be presented on maps and in tables that will be available via the Internet. In addition, we will apply and test the rule to mesoscale weather models (MM5) that currently operate in real-time support of fire weather predictions in Florida and the northwestern U.S.; making the rule available for regional fire-weather modeling with MM5 being planned in other parts of the country. Fire weather forecasters will be able to use these results to improve predictions of lightning-caused fire ignitions.

Introduction

This proposal addresses Task 6 of the 2/22/01 Joint Fire Science Program's Request for Proposals, which states, "Develop methods or systems for incorporating existing weather and climate predictions (ranging from short- to long-term) into tactical and strategic fire preparedness and planning." We plan to use observed and forecast upper-air meteorological data for fire preparedness and planning.

Lightning is a significant cause of wildfire in the United States. Whether or not an individual lightning strike results in an uncontrolled fire depends on many factors, including meteorological and fuel moisture conditions, and fire suppression efforts. It has long been recognized that fires are more likely to start and spread on days when conditions are dry and unstable. Nonetheless, no good methodology currently exists to identify which thunderstorms are more likely than others to cause fires. A previous study (Rorig and Ferguson 1999) has shown success in identifying dry, unstable days with a high risk of “dry” lightning (that which occurs without significant accompanying rainfall) in the Pacific Northwest. The method was successfully tested on the 2000 fire season (Rorig and Ferguson, 2001), identifying days with the most lightning-caused fire starts as days with the greatest probability of dry lightning. We propose to adapt these results to other areas of the country to create a useful, national product.

The relationship between thunderstorms, lightning, and fire has been studied for many years, with the goal of providing better forecasts of fire risk on public and private lands. As early as the 1920s studies were undertaken to identify the synoptic weather conditions that result in large numbers of lightning-caused fires in the state of Washington (Alexander 1927). Later studies investigated the association between flash polarity and fire ignition, theorizing that lightning strikes that lower a positive charge to the ground are more likely to have a long continuing current, and therefore are more apt to cause ignition (Fuquay et al. 1972; Fuquay 1980; Snyder 2001). Investigators also have tried to correlate synoptic weather patterns with thunderstorm activity and wildfire danger (Finklin 1981; Hill et al. 1987). The results of these previous studies indicate there is an important connection between atmospheric conditions and thunderstorms that ignite fires, but none have provided a simple methodology forecasters can use to assess the risk of dry thunderstorms.

Recently the National Centers for Environmental Prediction (NCEP) Storm Prediction Center has begun forecasting the potential for dry thunderstorms as part of its Fire Weather Program (Naden 2000). One of the forecast products is a map depicting convective available potential energy (an indicator of instability) and the average relative humidity in the lower part of the atmosphere. While this indicates where thunderstorms are expected and where there is a moisture deficit, there is no indication of how dry and unstable the conditions must be for dry lightning to be of concern to fire weather forecasters, and no estimation of risk.

In a previous study, we developed a discriminant rule to separate convective days into “dry” and “wet” categories based on the 850 hPa dewpoint depression and the 850-500 hPa temperature difference, and were able to assign a probability of dry lightning (Rorig and Ferguson 1999). This analysis was performed using data from Spokane, WA, and performed well when tested on independent data. In addition, we found a significant difference in the synoptic-scale 500 hPa patterns over the eastern Pacific and western North America between and dry and wet convective days. On dry days the mean 500 hPa trough was located west of the coastline, while on wet days the trough was situated over the Oregon and northern California coast (Figure 1). The mean 500 hPa heights were significantly higher on dry days than on wet days.

The objective of this work is to incorporate existing weather predictions into fire preparedness and planning by forecasting the risk of dry thunderstorms. This will be done by analyzing precipitation, upper-air, and lightning strike data to generate a discriminant rule that will be used to assess the risk of dry convection over the U.S. We will make available maps of risk for dry convection, based on available forecast products, which will be easily interpreted by forecasters and land managers. The benefits of this project are two-fold. In the short term, this work will lead to better quantification of the atmospheric component of fire risk. This will help land managers allocate resources more efficiently for fire planning purposes. Secondly, this work provides the potential for long-range predictability of climate conditions conducive to fire activity. If episodes of dry lightning can be linked to synoptic patterns, the potential exists to relate these patterns to longer-term global patterns such as the El Nino-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). This would provide an increased capability for generating seasonal-scale forecasts of fire risk.

Materials and Methods

The risk of dry lightning is highly dependent on vertical profiles of temperature and moisture in the atmosphere. We will obtain radiosonde data for the U.S. and derive dewpoint depression and temperature differences at three levels: 850, 700, and 500 hPa. Depending on terrain elevations, we will explore the use of other vertical levels as well. In addition, we will obtain daily precipitation and lightning strike data. The period of record will correspond to the availability of lightning strike data, which extends from 1986 until the present.

For each upper-air station, days will be segregated into convective and non-convective groups, based on the occurrence of lightning strikes within 10 km of the station. The convective days will be further grouped into dry and wet days, depending on the daily rainfall amount recorded at the station. A discriminant analysis will be performed to determine which variables are most effective in classifying the days (Mardia el al. 1979). A sample maximum likelihood discriminant rule will then be developed to assign the observations to one group or the other, and a probability of dry or wet convection will be computed as a function of those variables (see Figure 2). Several years of data within the 1986-2001 period of record will not be used to develop the discriminant rule, but will serve as a source of independent data for testing the rule.

When the methodology for determining dry lightning probability has been established, we will generate spatially distributed risk maps by applying the rule with data from numerical meteorological models. To complete U.S. coverage, we will experiment with prognostic models from the National Centers for Environmental Prediction (NCEP). For example, NCEP's Eta model covers most of North America (including Alaska) at 40 km to 22 km spatial resolution. Somewhat coarser data are available from NCEP's Reanalysis Model. This model provides historical information about the state of the atmosphere that can be used to determine spatial and temporal probability of dry lightning conditions throughout a 40-year period of record.

In Florida and the northwestern U.S., we will use values from the community MM5 mesoscale meteorological model for generating spatial maps of dry lightning risk. In these regions, MM5 is currently run in real-time (within hours after initialization) to help support fire weather and smoke management. The MM5 domain in Florida has a horizontal resolution down to 6 km, while the operational modeling domain in the Northwest is 4 km, with experiments using a 1 km horizontal resolution. In both regions, fire weather forecasters routinely use the MM5 products to help with daily predictions and spot weather forecasts. This allows an ongoing test and critique of the dry lightning rule from which we can tune or improve the rule to better fit regional conditions.

The MM5 model uses different numerical methods than the Eta model, thereby allowing more accurate predictions at fine scales over regions of complex terrain. For these reasons, several National Weather Service (NWS) forecast offices use and support MM5 modeling activities for enhancing fire weather forecasting capabilities. In addition, other regions of the country (2000 Fire Plan initiatives by Heilman, Actemeier, and Fujioka) are planning to implement regional, high-resolution modeling programs similar to those in the Northwest and Florida. Therefore, we expect that the implementation, use, and evaluation of our dry lightning discriminant rule in the Northwest and Florida MM5 systems will provide a prototype for implementation in other regional modeling domains.

To explore the relationship between dry lightning and synoptic meteorological patterns, we will generate maps of mean 500 hPa heights for dry and wet convective days. Because the potential for convection is not high everywhere in the U.S. on the same day, we will subdivide the country into sub-regions. We will determine whether significant differences exist in the locations of large-scale features such as troughs and ridges between the wet and dry 500 hPa patterns. This effort may allow monthly to annual predictions of dry lightning from predictions of ENSO and PDO impacts.

Dr. Sue Ferguson will oversee the project and collaborate on data analysis and technology transfer. Ms. Miriam Rorig will be primarily responsible for data acquisition and analysis, and development of the methodology used to assess risk. Dr. Scott Goodrick will help implement the dry lightning discriminant rule into Florida's MM5 product. Both Dr. Goodrick and Mr. Paul Werth will ensure that the climate analyses of dry lightning probabilities in the southeastern and northwestern U.S., respectively, are physically reasonable and will help evaluate the MM5 predictions of dry lightning probability in Florida and the northwestern U.S.

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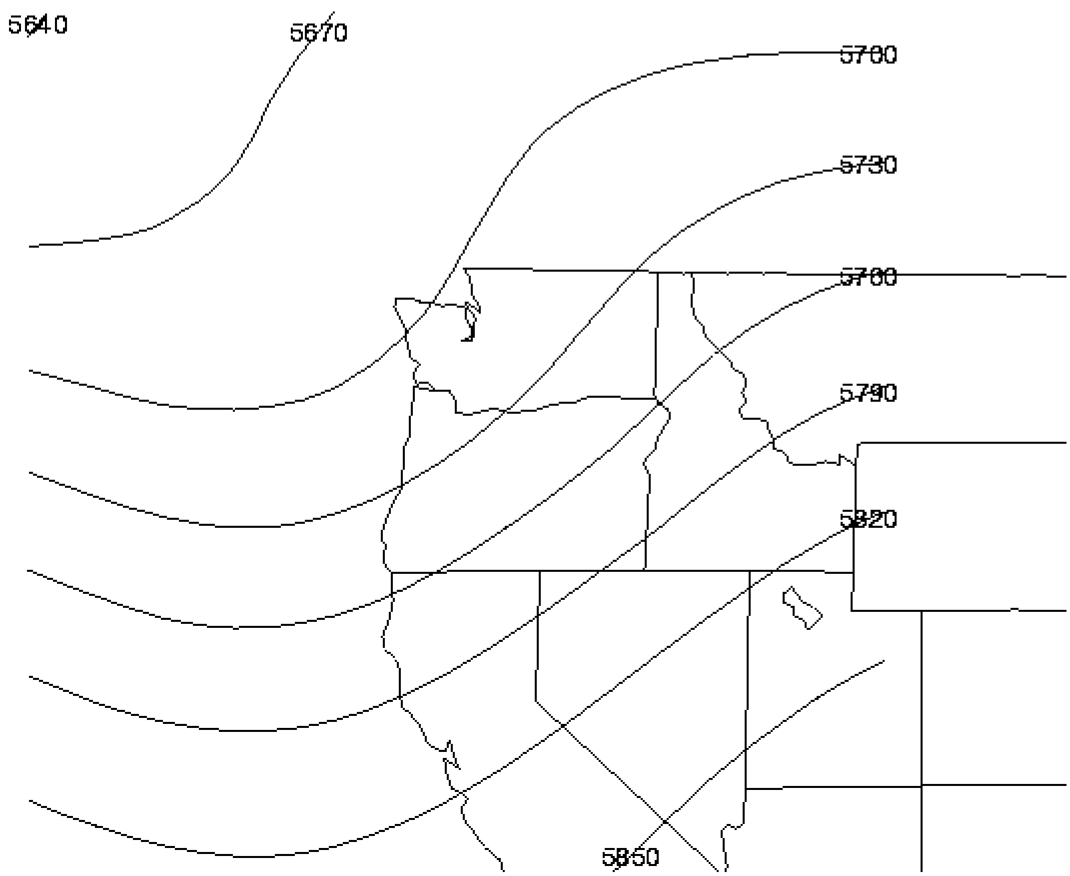
Figures

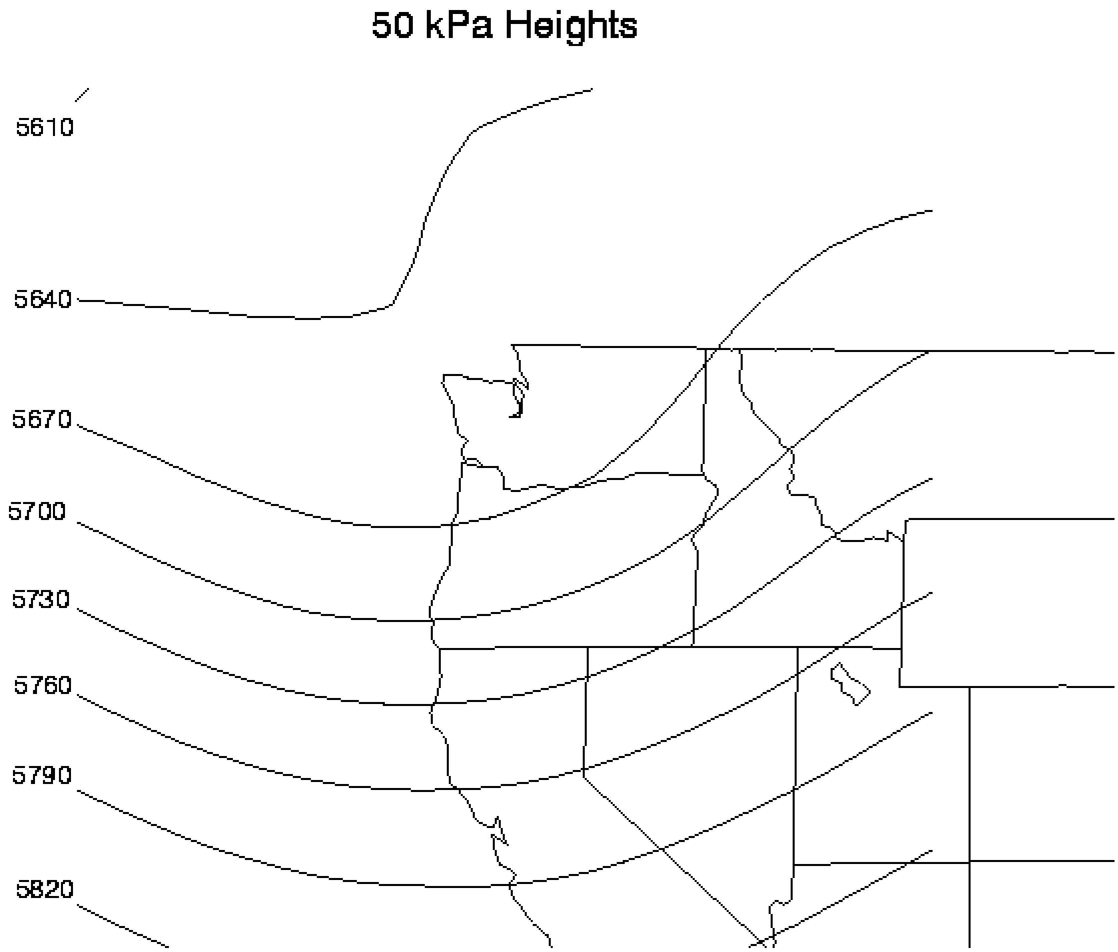
Figure 1. Mean 500 hPa heights (m) for thunderstorm days at Spokane, 1948-77 for (a) dry days, (b) wet days, and (c) dry – wet days.

Figure 2. Probability of a thunderstorm day belonging to the wet or dry group based on 850 hPa dewpoint depression (DD850) and 850 – 500 hPa temperature difference (T8 – T5).

50 kPa Heights

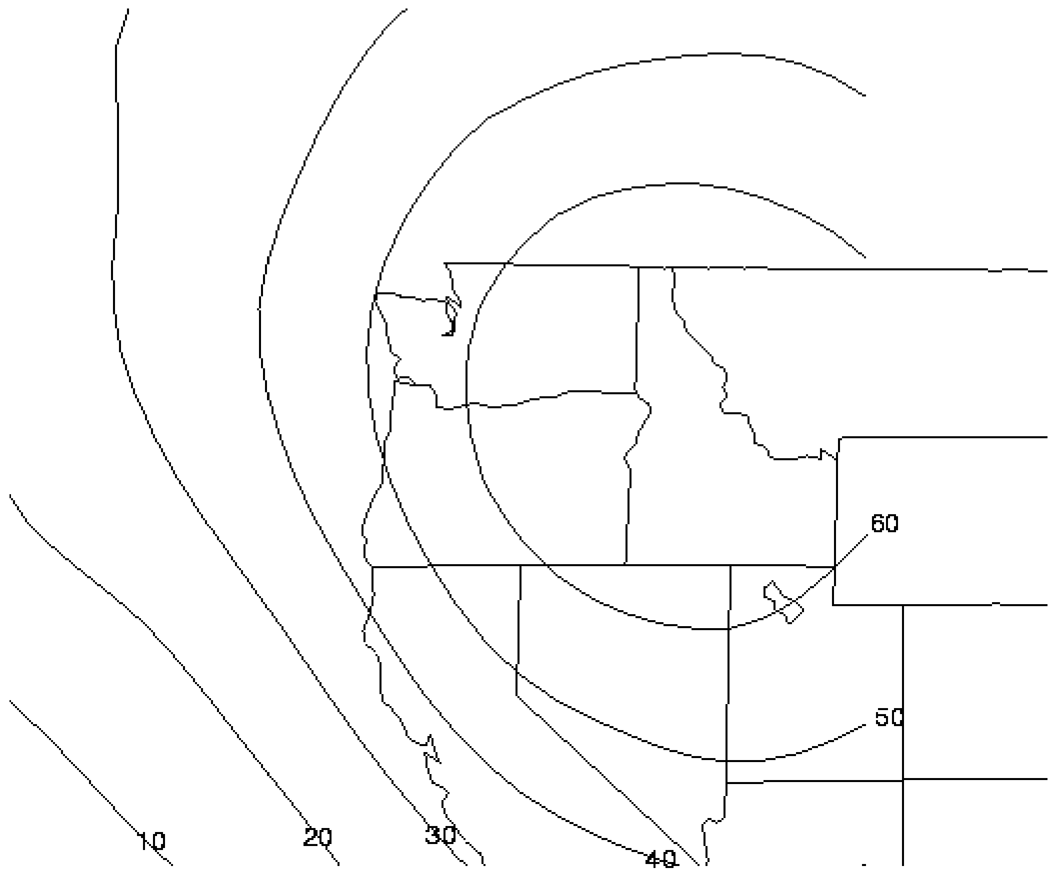


a. Dry thunderstorm days

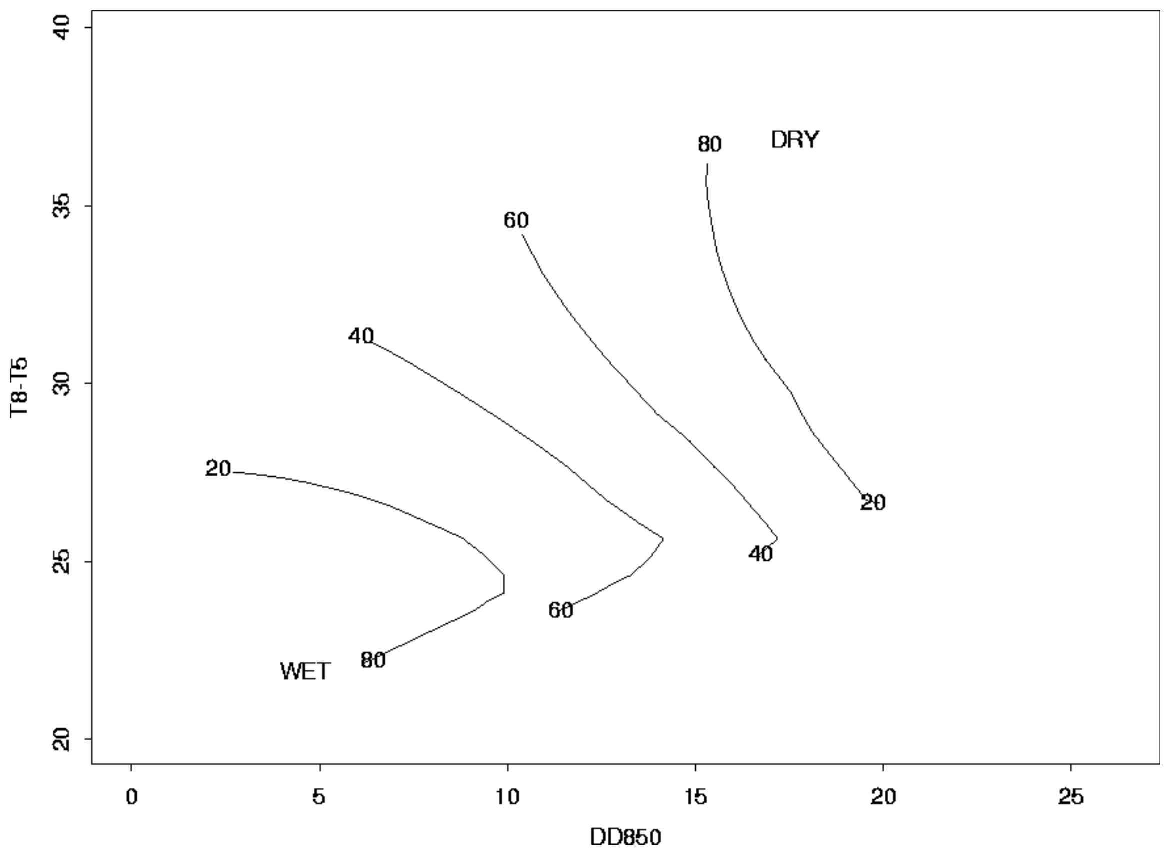


b. Wet thunderstorm days

50 kPa Height Differences



c. Dry-wet thunderstorm days



DRY
WET
80
60
40
20
T8-T5
DD850